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Agricultural Memorandum No 886

Modelling the field drying of hay III: Simulation of swath drying by a multi-layer swath model when rain and dew occur during the drying period

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1. Introduction An earlier Agricultural Memorandum (Thompson 1979a) discussed the application of a multi-layer swath model to the field drying of hay in situations where the swath remained dry during the simulation. Shortcomings in the model which prevented its application to periods which included rainfall and dew have now been eliminated and the results from this revised model will now be described.

2. The Model Full details are given by Thompson (1979b, 1979c). The model simulates a uniformly distributed swath lying on an underlayer of transpiring and dead stubble and losing or gaining moisture in response to the appropriate environmental factors. The canopy of swath and stubble is divided into a number of equal layers (usually 8) and water losses or gains calculated for each layer using a resistance sub-model. Moisture is lost or gained by the swath according to whether the equiliberum humidity of the swath (a function of tissue water content) is greater or less than the relative humidity of air in the layer. Once the swath stomata close the swath layer resistance is assumed to be constant; however the resistance may be made a function of layer water content and simulations will be described also for variable layer resistances. The model calculates dewfall and intercepted rainfall and will cope with, for example, the simultaneous absorption of moisture by the swath when its surfaces are wet, and evaporation of the surface water into the free atmosphere. Tedding is treated by assuming that this produces a uniform distribution of surface and swath (tissue) moisture through the swath. The moisture budget of the swath and stubble is calculated at half-hourly intervals using meteorological data interpolated from hourly synoptic observations.

3. Data

3.1 The crop

Crop variables are listed in Table 1. A constant swath leaf area index is assumed throughout the simulation, although in practice the leaves will shrivel and shrink as they dry , so reducing their area.

Table 1 Crop variables

Swath dry weight	5 tonnes/ha
Moisture content at cutting	400% (dry basis)
Swath leaf area index	5
Green stubble leaf area index	0.5
Dead stubble leaf area index	0.5
Initial water content of dead stubble	50%
Swath water content at stomatal closure	200%
Maximum intercept per unit LAI	0.2 mm
Swath leaf resistance (closed stomata)	5000 sm^{-1}

Table 1 (continued)

Depth of untedded swath	0.08m
Depth of tedded swath	0.20m
Base of untedded swath	0.03m
Base of tedded swath	0.04m
Stubble height	0.05m
State of soil surface	Dry
Time of cut	0900, 14 May 1971
Number of teddings	8
Times of teddings (hours after start of simulation)	5,26,52,76,98,102,120,124

3.2 Meteorological data

The model was run using a sequence of data about 130 hours long from Abingdon observations in May 1971. Details are given in Table 2. The period selected is rather early in the year for haymaking but was chosen in order to obtain a suitable set of data to test most aspects of the model. Much of the period was favourable for swath drying, especially later when low daytime relative humidities were consistently recorded, but there were two cloudier interludes with some rain.

Table 2 Meteorological data (Abingdon)

First observation	0900, 14 May 1971
Last observation	1600, 19 May 1971
Periods of rain	1500-2200, 15 May (3.3 mm)
	0300-0600 17 May (0.9 mm)
Minimum and maximum relative humidities	14th: 61/86
	15th: 65/97
	16th: 38/96
	17th: 48/90
	18th: 40/97
	19th: 45/86

Weather:

14th:	Long sunny periods
15th:	Generally clear night, then increasing cloud with rain later
16th:	Cloudy night followed by bright day with increasing cloud in evening
17th:	Overcast with rain early morning, followed by decreasing cloud and clear evening.
18th:	Clear night and sunny day
19th:	Clear night and sunny day

4. Results Figure 1 summarises the results from the simulation using a constant value for swath resistance after stomatal closure. The main graph shows the internal (tissue) water contents (W) of the bottom and top layers of the swath (values for the other 6 layers were usually intermediate between those for layers 1 and 8). The sub-graphs give the surface water intercepted by the swath from rain or dew. The main features of the results may be summarised as follows:

(i) (all swath stomata open) In this initial stage of drying water losses from the top layers are rapid, but much slower at the base of the swath where humidity is high and level of radiation is low.

(ii) (progressive closure of stomata from top layers downwards, completed by about 1400 on 14 May) When the stomata in a layer close, the layer's bulk

resistance is assumed to rise immediately to a much higher value with an increase in temperature in order to dissipate the available energy, now chiefly as sensible heat rather than the latent heat when the stomata were open. This increases the vapour pressure deficit in the layer and encourages an increasing rate of evaporation in the layers below, where stomata still remain open.

(iii) (stomata closed, no surface moisture) Continued drying now depends on a sufficiently low relative humidity in the swath. The equilibrium humidity decreases as the swath becomes drier and the actual R H has to decrease therefore to maintain a significant rate of drying. When the swath moisture content is high (eg 14 May) the time of changeover from swath drying to swath moistening (in response to the typical increase of RH in the swath from mid afternoon onwards) occurs later therefore (around 2200) than when the swath is very dry (eg on 18th when the upturn occurs at around 1800). A feature of the process is that, for a fairly dry swath. the distribution of internal moisture changes as the night advances: initially the upper layers are driest, but then a crossover occurs so that by the end of the night these layers are the most moist. This is a consequence of the way the swath's energy balance is maintained at night, with net radiation upwards and greatest cooling in the upper swath layers, while an upward flux of heat from the soil maintains a higher temperature and lower relative humidity at the base of the swath: thus the moisture uptake by the swath at night is least at its base. When the swath becomes very dry (eg by the 18th) then tedding is essential to produce a reasonably uniform distribution of moisture. For example after the tedding at 1500 on the 18th the top layer continued to dry until 1700 but the bottom layer was already taking up moisture, reflecting the increasing importance of high relative humidity at the base of the swath in the later stages of drying. In less favourable conditions than the excellent ones which occurred in the latter part of the simulation the relative humidity at the swath base will be substantially higher and it will be impossible to achieve acceptable swath drying without tedding because moisture loss at a reasonable rate will only occur from the upper part of the swath.

(iv) (stomata closed, dew forming) The model calculate the formation of dew chiefly during the early morning on 15th and 18th, but only in the upper part of the swath. Subsequent evaporation after sunrise is rapid therefore and relative humidity decreases quickly in all the swath layers.

(v) (stomata closed, swath wetted thoroughly by rain) Evaporation of water from crop canopies after rain is much slower in the lower layers (Thompson 1980) which dry out several hours later than the top layers. Thus swath moisture (tissue) content will begin falling at the top of the swath while water is still being taken up at the base (eg 16/0900 to 16/1300, 17/0800 to 17/1000). In these circumstances the upper layers will become substantially drier than the lower parts and a tedding is needed to maintain a reasonably consistent drying of the swath.

Figure 1 demonstrates that the swath eventually becomes exceptionally dry, probably unrealistically so in spite of the excellent drying conditions. The model was re-run therefore, using the same set of input data but now with a swath leaf resistance (r) after stomatal closure a function of swath water content W(%) according to the relation

$$r = 5000\ (0.84 + 0.32\ (\tfrac{100}{W}))\quad sm^{-1} \qquad (1)$$

: the resistance then increases from 5000 sm^{-1} for W = 200% to around 7500 at 50% moisture content and about 12000 sm^{-1} at 20% content. This postulated behaviour is hypothetical and not supported by experimental data but will at

least produce a substantially lower drying rate in the later stages of drying. It will also lead to a lower rate of uptake of moisture than before when the humidity rises, which may be less realistic. Results from a re-run of the model with this variable swath leaf resistance appear in Figure 2 (without sub-graphs showing intercepted water, which are very similar for both fixed and variable swath resistances). Not unexpectedly the general pattern of variation of swath moisture with time is rather similar to that shown in Figure 1, but now the stage of extreme dryness of swath found earlier is no longer reached. Final calculated moisture contents somewhat less than 20% are probably similar to those which would be found in a similar field situation. It is interesting to see the marked reduction in moisture uptake by the swath on the night of 18/19th which is a consequence of the substantially higher swath resistance used in the second simulation.

5. Concluding remarks Results from the model appear to be in broad agreement with field experience. Use of a variable swath (leaf) resistance whose value depends on swath moisture content probably gives the more realistic result but a choice between this and say a fixed resistance somewhat higher than 5000 sm^{-1} would require a careful comparison with experimental data. In spite of the relative simplicity of the model it appears to model satisfactorily, at least qualitatively, a typical haymaking sequence involves tedding, rainfall and dew formation. It is expected that the model will be tested soon against experimental data and its performance compared with that of the simple bulk model described by Thompson (1979c).

Any comments or suggestions on this paper should be referred to the author.

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References

Thompson, N 1979a Agricultural Memorandum No 871
1979b Agricultural Memorandum No 842
1979c Agricultural Memorandum No 870
1980 Agricultural Memorandum No 884

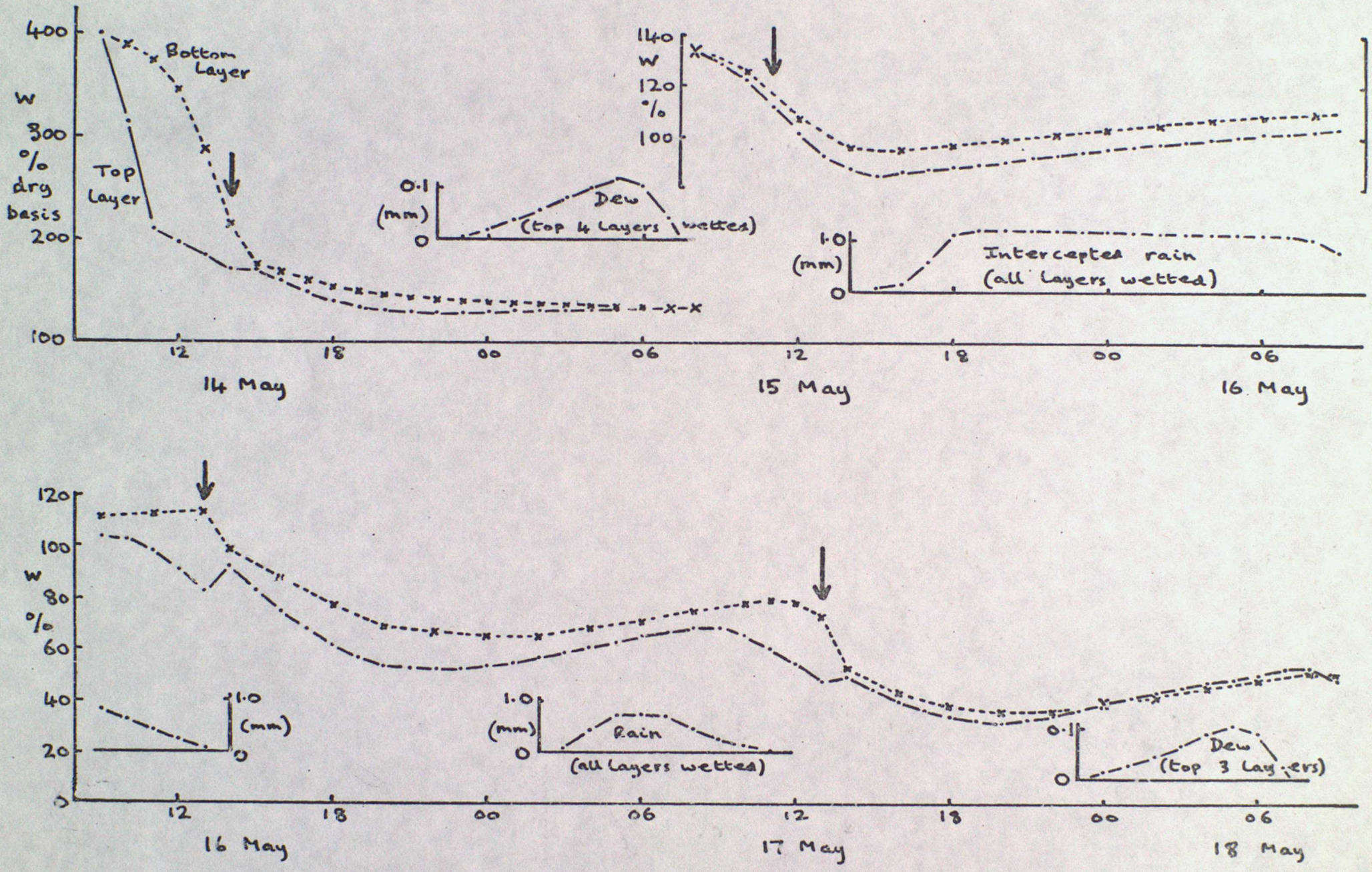

Figure 1 Swath layer water contents, and intercepted water (teddings are shown by vertical arrows)

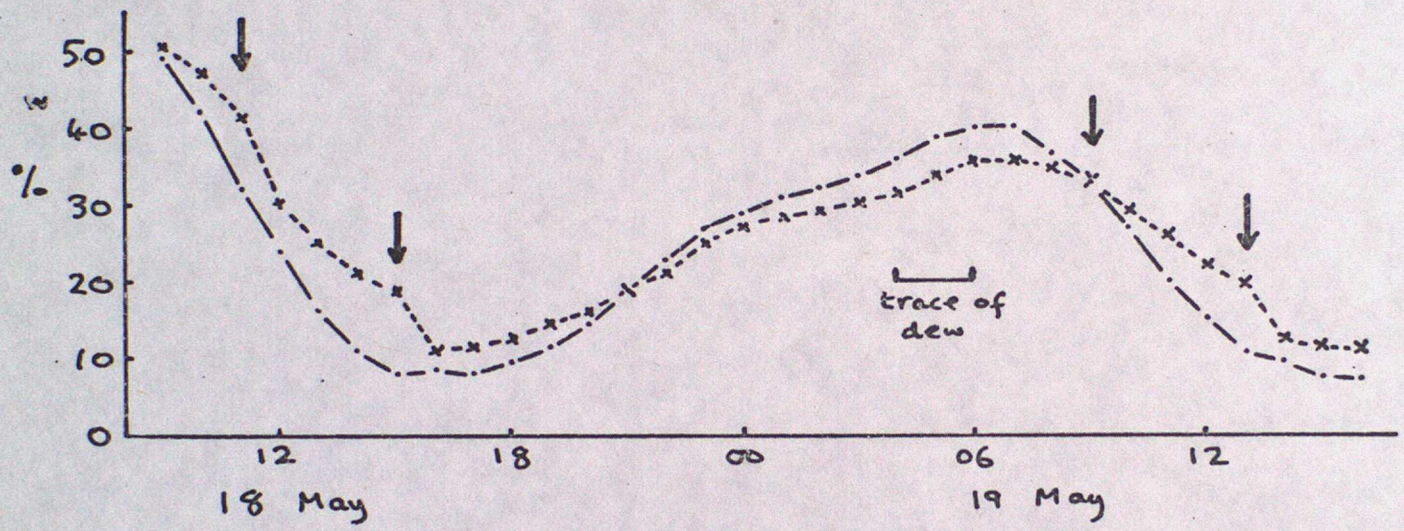

Figure 1 (continued)

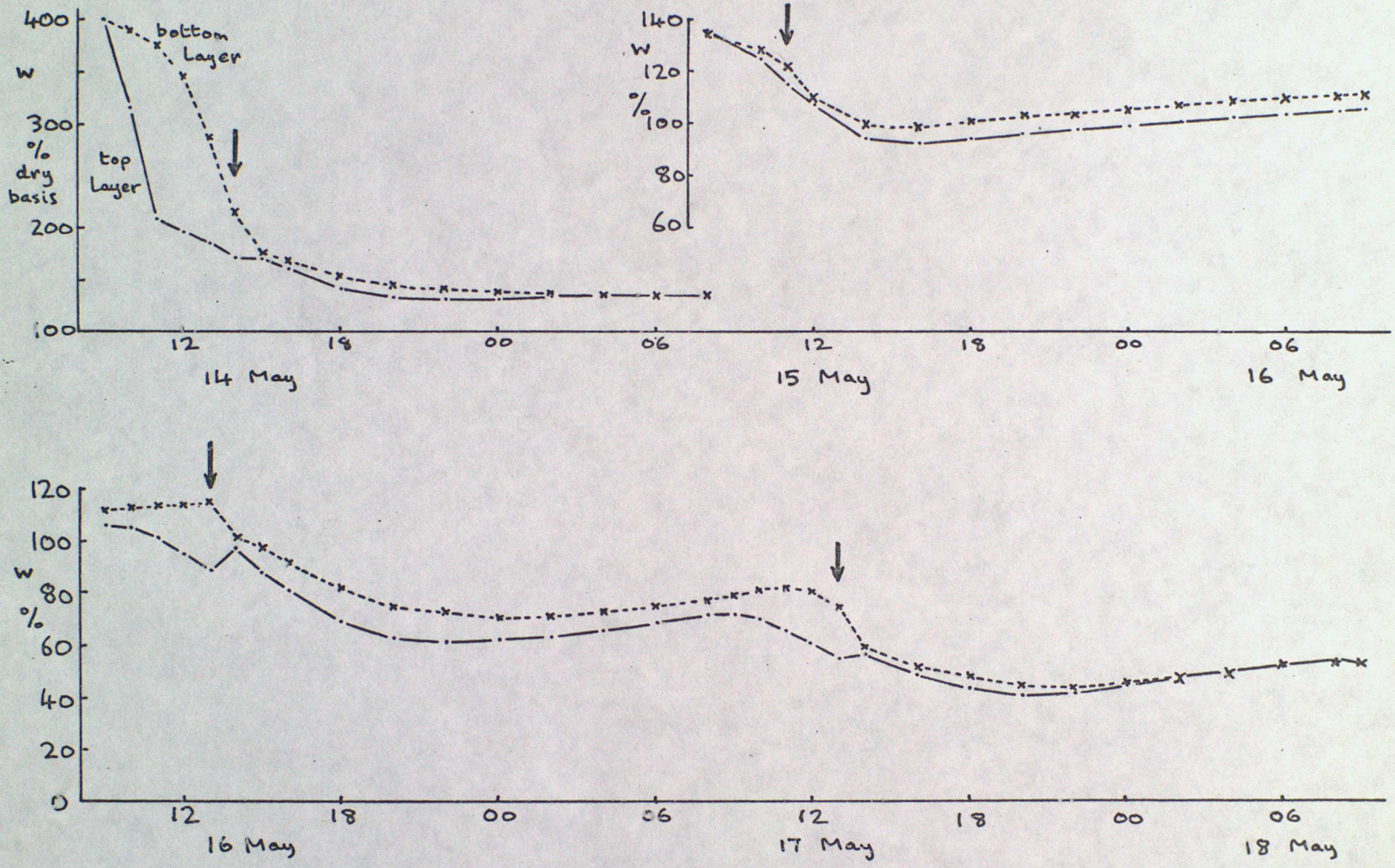

Figure 2 Water contents using variable swath resistance

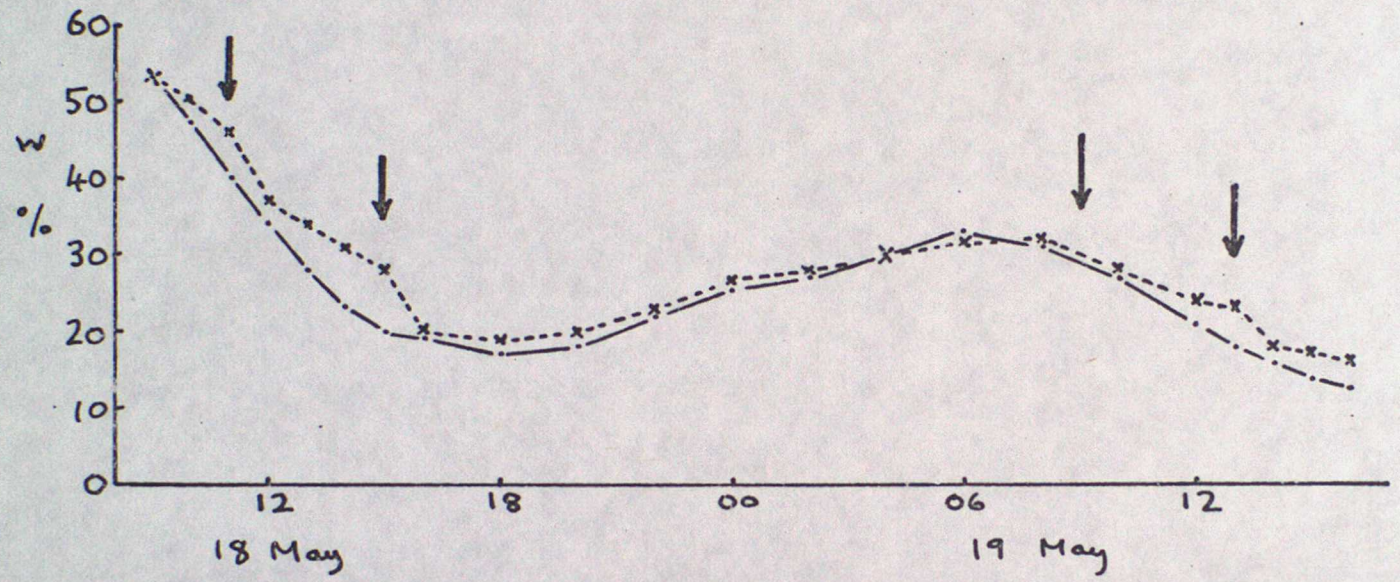

Figure 2 (continued)